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(54) Method and apparatus for monitoring processes using multiple parameters of a semiconductor wafer processing system

(57) The disclosure relates to a method and apparatus for providing process monitoring within a semiconductor wafer processing system (100) using multiple process parameters. Specifically, the apparatus includes a signal analyzer (122) which analyzes multiple process parameters from generators (108, 110, 114, 120) and statistically correlates these parameters to detect a change in process characteristics such that the endpoint

of an etch process may be accurately detected; as well as detecting other characteristics within the chamber (102). The multiple parameters may include optical emissia, environmental parameters such as pressure and temperature within the reaction chamber, RF power parameters such as reflected power or tuning voltage, and system parameters such as particular system configurations and control voltages.

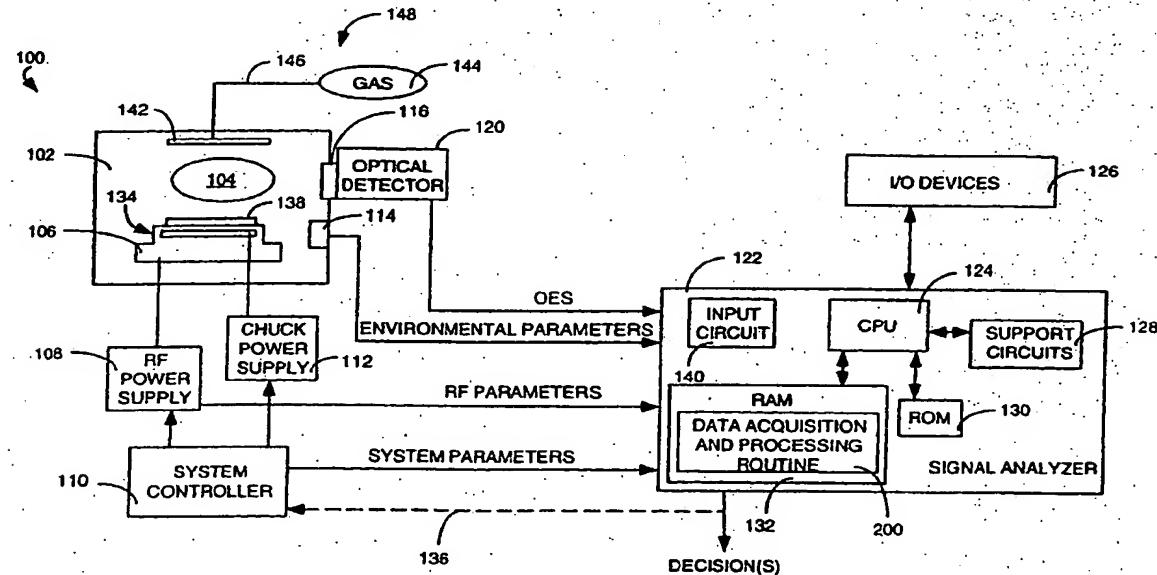


FIG. 1

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Description

The invention relates to semiconductor wafer processing systems and, more particularly, to a method and apparatus for performing in situ monitoring of process parameters of a semiconductor wafer processing system.

Plasma enhanced processes that occur within a semiconductor wafer processing system are generally designed to run for a specific length of time and are monitored using an optical emissions spectroscopy (OES) technique. The OES equipment couples to a transparent window of a reaction chamber containing the plasma. The OES equipment monitors the optical emissions from the plasma. Typically, a single wavelength is extracted (filtered) from all of the emissia of the plasma, and the magnitude of the signal at the extracted wavelength indicates the present chemistry within the chamber. A change in this chemistry will increase or decrease the magnitude of the signal at the extracted wavelength and, as such, indicate a change in the process occurring within the chamber.

For example, a plasma in a dry etch process is typically monitored by extracting the carbon monoxide (CO) emission line at 4835 angstroms. A change in the magnitude of the carbon monoxide line is indicative of the endpoint of an oxide etch process.

Extracting a particular line, as well as suppressing the noise generated by the plasma at other wavelengths, requires substantial signal processing and careful OES equipment fabrication and calibration. Such endpoint detection requires the detection of a very small change in signal strength at a particular optical wavelength. As such, the desired signal is easily corrupted by noise. If care is not taken while monitoring the process, the endpoint may not be detected, and the wafer will be overetched. Such overetching may destroy the integrated circuits on the wafer and reduce the yield of the semiconductor wafer processing system.

Therefore, there is a need in the art for improved monitoring techniques for a semiconductor wafer processing system and especially for detecting etch endpoint as well as other process characteristics within a reaction chamber.

The disadvantages associated with the prior art are overcome by the present invention of a method and apparatus that monitors processes performed by a semiconductor wafer processing system using multiple process parameters. Specifically, the present invention analyzes multiple process parameters and statistically correlates the parameters to detect a change in process characteristics such that the endpoint of an etch process may be accurately detected, as well as detecting other process characteristics within a chamber. The multiple parameters may include plasma optical emissia, environmental parameters such as pressure and temperature within the reaction chamber, RF power parameters such as reflected power or RF match tuning voltage, and

system parameters such as particular system configurations and control voltages.

More specifically, the invention contains a statistical engine which correlates all of the relevant parameters for a particular system configuration, and when a particular number of parameters indicate a specific change in characteristics within the reaction chamber, the statistical engine produces a decision which may indicate completion of a particular wafer process. For example, the decision may indicate that the etch endpoint has been attained, may indicate that the chamber requires cleaning, or may indicate some other task needs attention. These decisions may be coupled to a system controller such that feedback is provided to the system controller to facilitate integrated control of the entire semiconductor wafer processing system.

The statistical engine is an executable software program generally executed on a general purpose computer system. However, the statistical engine could be a subroutine that is executed within the microprocessor of the system controller.

The statistical engine forms part of a data acquisition and processing routine that acquires data from various sensors within the semiconductor processing system, correlates that data across the various measured parameters, and periodically stores the correlated data. A previous wafer's correlated data is compared to the present wafer's correlated data to determine a correlation trend from wafer-to-wafer. If the correlation trend exceeds a particular threshold, a wafer-to-wafer flag is set. Depending upon the parameters that are correlated to produce the trend, such an indication may lead to the requirement that the chamber be cleaned. The correlation data for the presently-processed wafer is also compared to a decision threshold to determine whether or not, for example, the etch endpoint has been attained for the present wafer. If the endpoint has not been attained, the query is answered negatively, and the routine continues to acquire data and correlate the data on a periodic basis throughout the processing of the present wafer. At a point where the decision is made that the endpoint has been reached, the process is stopped, and then the routine queries whether another wafer should be processed. If the wafer-to-wafer flag has been set, another wafer will not be processed, and the routine will enter a new processing phase, e.g., cleaning the chamber. If a new wafer is required, the routine will move to acquire data with respect to the next wafer.

By correlating multiple parameters, the signal to noise ratio (SNR) of the correlated signal is substantially improved over the SNR of any single parameter. As such, smaller process changes can be detected and action, in response to those changes, can be rapidly taken. Moreover, correlation trend monitoring not only provides wafer processing characterization but system characterization as well.

The teachings of the present invention can be readily understood by considering the following detailed de-

scription in conjunction with the accompanying drawings, in which:

FIG. 1 depicts a block diagram of a semiconductor wafer processing system containing a multiple parameter signal analyzer in accordance with the present invention; and

FIG. 2 depicts a flow diagram of a data acquisition and processing routine.

To facilitate understanding, identical reference numerals have been used, where possible, to designate identical elements that are common to the figures.

FIG. 1 depicts a block diagram of a semiconductor wafer processing system 100 coupled to a signal analyzer 122 of the present invention. The semiconductor wafer processing system 100 contains a reaction chamber 102 having a wafer support pedestal or susceptor 106, an RF power supply 108, a chuck power supply 112, a reactive gas supply assembly 148 and a system controller 110. The susceptor 106 supports the wafer 138 in the chamber. The susceptor 106 contains, for example, an electrostatic chuck 134 for biasing the wafer and retaining it upon the support surface of the susceptor. The chuck is powered by the chuck power supply 112. The susceptor also forms a cathode for the plasma generation system. The cathode is coupled to the RF power supply 108. For example, in an etch system, a plasma is generated by coupling the RF power to a reactive gas. The reactive gas assembly contains a gas supply 144 that supplies a reactive gas via conduit 146 and manifold 142 to the chamber 102. To ignite the plasma, RF power is applied to the cathode. The chamber walls are grounded, and the electric field between the chamber walls and the cathode ignites a plasma 104 within the reaction chamber.

The chuck electrode voltage and the RF power levels are controlled by the system controller 110. The plasma performs plasma-enhanced dry etching of the surface of the semiconductor wafer 138. This simplistic drawing of a semiconductor wafer processing system is intended to be illustrative of the major components of the system.

Signal analyzer 122 acquires data from a number of sources within the semiconductor wafer processing system. For example, optical emission of the plasma 104 are passed through a transparent window 116 to the optical detector 120. The optical detector 120, positioned outside the chamber 102 directly in front of the window 116, converts the optical energy that is coupled through the window into a voltage. The voltage is coupled as one parameter (e.g., an optical emission spectroscopy (OES) parameter) to the signal analyzer. The optical detector may be of many types such as a bandpass photon detector or a photomultiplier tube using a monochromator to select a particular optical wavelength for detection.

The RF power supply 108 generates RF parameters. These parameters include reflected power or the

tuning voltage used to tune the match unit to the impedance of the plasma. Changes in the reflected power and/or the tuning voltage are indicative of chemistry changes within the chamber.

5 The system controller 110 provides control signals to the RF power supply 108 and the DC chuck power supply 112. Additionally, it generates system parameter signals which are coupled to an input circuit 140 of the signal analyzer 122. The chamber may also include a 10 number of environmental sensors 114 such as temperature sensors, foreline and chamber pressure sensors, reactive gas analyzing sensors and the like. These sensors generally produce analog voltages that are also coupled to the input circuit 140. The input circuit synchronizes, digitizes and buffers the data, as needed.

15 The signal analyzer 122 is typically a general purpose computer having a central processing unit (CPU) 124, a plurality of input/output devices 126, support circuits 128 (e.g., power supplies, clock circuits, bus controllers, cache, and the like), read only memory (ROM) 130, and random access memory (RAM) 132. The interrelation and operation of these components of a general purpose computer are well known in the art.

20 The signal analyzer correlates all or a subset of the parameters that are provided as input to the analyzer. The data acquisition and processing routine 200 is an executable software program which generally resides in RAM 132 as it is executed by the CPU 124. Decisions made in response to processing the parameters are provided as an output of the signal analyzer 122. These 25 decisions may be coupled along path 136 to the system controller for implementation. As such, the system controller may react to these decisions by ending processing, if an endpoint detection is determined, or initiating a cleaning function, if cleaning of the chamber is deemed required. The parameters and correlated data 30 may also be stored in the RAM 132 for historical review of processing trends. As such, new parameters may be determined for future monitoring.

35 40 Although the signal analyzer 122 is described herein as being a stand alone general purpose computer that is programmed to perform the data acquisition and processing functions, these functions may be incorporated into the system controller 110 and executed on the microprocessor of the system controller.

45 By correlating a number of signals and/or parameters that are monitored by the signal analyzer, the signal-to-noise ratio (SNR) of the correlated parameters is increased over the SNR of any one parameter signal alone. As such, for a number of parameters, the parameters are known to simultaneously change at a particular 50 point during processing of the wafer. All of those changes can be correlated such that the detected signal is much larger than the underlying noise of the system. For example, a pressure change at the endpoint in a photoresist strip process can be correlated with the RF parameters that change due to a decrease in a chamber pressure. Such a pressure decrease causes the match

control unit to change the control voltage to insure that the RF power is matched to the new chamber pressure. Further, a signal is provided by the system controller to change the gas flow rate from the gas supply 144. In addition, at the point in a photoresist strip process when the pressure changes, the plasma optical emissia also will change. Thus, these three parameters (e.g., chamber pressure, match control voltage and optical emissions) can be correlated to best indicate the endpoint has been reached in a photoresist strip process. Additionally, these correlated signals as well as others can be monitored from wafer-to-wafer such that trends in the correlated signals can be detected. Such trends are indicative of build-up of impurities and deposits within the chamber. When these wafer-to-wafer correlated signals exceed a certain threshold, the chamber can be deactivated and a cleaning process engaged.

To further improve the decision making properties of the signal analyzer, well-known techniques for decision making can be used such as fuzzy logic, neural networks or stochastic processing.

FIG. 2 depicts a signal acquisition and analysis routine 200 that is executed by the signal analyzer (122 of FIG. 1). The routine begins at step 202 and proceeds to step 204 wherein the data representing the various parameters is acquired. Data acquisition occurs by the signal analyzer 122 periodically polling the various parameter sources for input circuit data. Alternately, the data may be provided to the input circuit on an interrupt basis or as a combination of polling and interrupt. Depending upon the characteristic that is being monitored, all or a subset of the parameters may be used in the data correlation and processing steps.

Using a statistical engine 224, all of the parameters selected to provide information for a particular process are correlated with one another and stored in memory at step 206. The statistical engine 224 also performs, at step 208, a wafer-to-wafer correlation; wherein correlated data from previous wafers at this point in the process are compared to the presently acquired correlated data in an effort to statistically determine a trend in the wafer-to-wafer correlated signals. The wafer-to-wafer correlation may also be performed by comparing the presently acquired correlated data to a theoretical model of expected values. The trend is indicative of a chamber that contains impurities and requires cleaning. As such, the wafer-to-wafer correlation signal is compared to a threshold at step 210, and if the correlation signal exceeds the threshold, the routine sets a wafer-to-wafer flag. This flag indicates whether the chamber requires cleaning, or some other process, after the present wafer has completed processing.

The threshold values and correlated signals are preferably expressed as a ratio of monitored parameters. For example, the signal analyzer 122 receives signals representative of source tuning (ST), load (SL) and current (SI) levels and bias tuning (BT), load (BL) and current (BI) levels. Calculation of the expression $C =$

$(STxBTxSI)/(SLxBLxBI)$ results in a value for determining if chamber cleaning is required. Specifically, if $1 < C < 2$, then the chamber is functioning within its normal operating range. If $C < 1$, this condition indicates a hardware failure in the system. If $C > 2$, then the chamber has exceeded sanitary limits and must be cleaned. Alternately, the ratio of carbon to fluorine can be monitored against a theoretical value programmed into the signal analyzer. If the observed ratio departs from the theoretical value, this also indicates that the chamber must be cleaned.

At step 212, the correlated data for the presently processed wafer is compared to a threshold, and the routine decides whether to continue processing or to cease processing for this particular wafer. For example, if an etch endpoint is to be detected and the correlated signal does not exceed the threshold indicating the endpoint has been attained, the routine will proceed along the NO path 220 to continue the etch process and acquire data at the next data acquisition period using step 204. This loop is repeated until a decision is made that the endpoint has been attained, and at that point, the query block of step 212 will proceed along the YES path to step 214.

At step 214, the signal analyzer will cause the system to react to the decision. Such a reaction may be as simple as illuminating an indicator lamp indicating that the endpoint has been attained, or it may require a signal to be sent to the system controller to automatically deactivate processing. At step 216, the routine queries whether another wafer will be processed. If the query at step 216 is affirmatively answered, the routine proceeds along path 222 to acquire more data with respect to the next wafer. If another wafer is not to be processed, i.e., the wafer-to-wafer flag is set indicating that the chamber is due for a cleaning process, the routine exits at step 218.

In sum, a semiconductor wafer processing chamber is monitored by a signal analyzer that accepts environmental and system parametric data during wafer processing to detect changes in wafer processing characteristics. Depending on this data, the signal analyzer determines optimal wafer processing conditions and reacts accordingly. Specifically, a statistical engine correlates two or more of the parameters to determine completion of a particular process. The correlation of two or more signals reduces the overall signal-to-noise ratio thereby improving detection of a desired process condition (i.e., wafer processing endpoint). Additionally, the correlated data can be compared to previous data or a baseline theoretical model to determine trends that occur during processing. The trends are indicative of chamber characteristics that require correction or evaluation for improved wafer processing (i.e., chamber cleaning required or additional parameters monitorable for increased accuracy in endpoint detection). As such, a more precisely manufactured product (i.e., a semiconductor wafer) is produced under improved manufac-

ing conditions.

Although various embodiments which incorporate the teachings of the present invention have been shown and described in detail herein, those skilled in the art can readily devise many other varied embodiments that still incorporate these teachings.

Claims

1. A method for monitoring semiconductor wafer processing system parameters comprising the steps of:
 - acquiring parametric data indicative of system characteristics;
 - correlating said data from various sources of parametric data to form a correlation signal;
 - defining a trigger criterion corresponding to a particular value of said correlation signal to form a trigger point;
 - comparing said correlation signal to said trigger point to determine the existence of a specific characteristic within the system; and
 - reacting to said comparison.
2. A method as claimed in claim 1, wherein the parametric data is acquired by a plurality of sensors connected to the semiconductor wafer processing system.
3. A method as claimed in claim 2, wherein one of the sensors detects optical emission of plasma in the semiconductor wafer processing system.
4. A method as claimed in claim 2 or claim 3, wherein one of the sensors detects RF reflected power or tuning voltage.
5. A method as claimed in any of claims 2 to 4, wherein one of the sensors detects temperature in the semiconductor wafer processing system.
6. A method as claimed in any of claims 2 to 5, wherein one of the sensors detects pressure in the semiconductor wafer processing system.
7. A method as claimed in any of claims 2 to 6, wherein one of the sensors detects reactive gas analyzer signals in the wafer processing system.
8. A method as claimed in any of claims 1 to 7, wherein the trigger criterion is defined by a simultaneous change in two or more wafer processing system parameters.
9. A method as claimed in any of claims 1 to 8, wherein the step of correlating data is accomplished by a

signal analyzer that accepts input of the parametric data and provides output of control signals to a wafer processing system controller.

- 5 10 15 20 25 30 35 40 45 50 55 60 65 70 75 80 85 90 95
10. An apparatus for monitoring a wafer processing system (100) using multiple process parameters comprising:
 - a plurality of wafer processing system parameter signal generators (108, 110, 114, 120) producing a plurality of parameter signals;
 - a signal analyzer (122) connected to said wafer processing system parameter signal generators (108, 110, 114, 120) for correlating two or more parameters, and
 - at least one decision output signal (136) from the signal analyzer (122).
11. An apparatus as claimed in claim 10, wherein one of the signal generators is an optical sensor (120).
12. An apparatus as claimed in claim 10 or claim 11, wherein one of the signal generators is an RF reflected power or tuning voltage sensor (108).
13. An apparatus as claimed in any of claims 10 to 12, wherein one of the signal generators is a temperature sensor (114).
14. An apparatus as claimed in any of claims 10 to 13, wherein one of the signal generators is a chamber pressure sensor (114).
15. An apparatus as claimed in any of claims 10 to 14, wherein one of the signal generators is a reactive gas analyzer (114).
16. An apparatus as claimed in any of claims 10 to 15, wherein one of the signal generators is from a wafer processing system controller (110) having an input of the decision output signal (136) from the signal analyzer (122) and a plurality of outputs connected to the wafer processing system.
17. An apparatus as claimed in claim 16, wherein one of the outputs is an input to an RF power supply (108).
18. An apparatus as claimed in claim 16 or claim 17, wherein one of the outputs is an input to an electrostatic chuck power supply (112).
19. An apparatus as claimed in any of claims 16 to 18, wherein one of the outputs is an input to a gas supply (144).
20. An apparatus as claimed in any of claims 10 to 19, wherein the signal analyzer (122) is a general pur-

pose computer.

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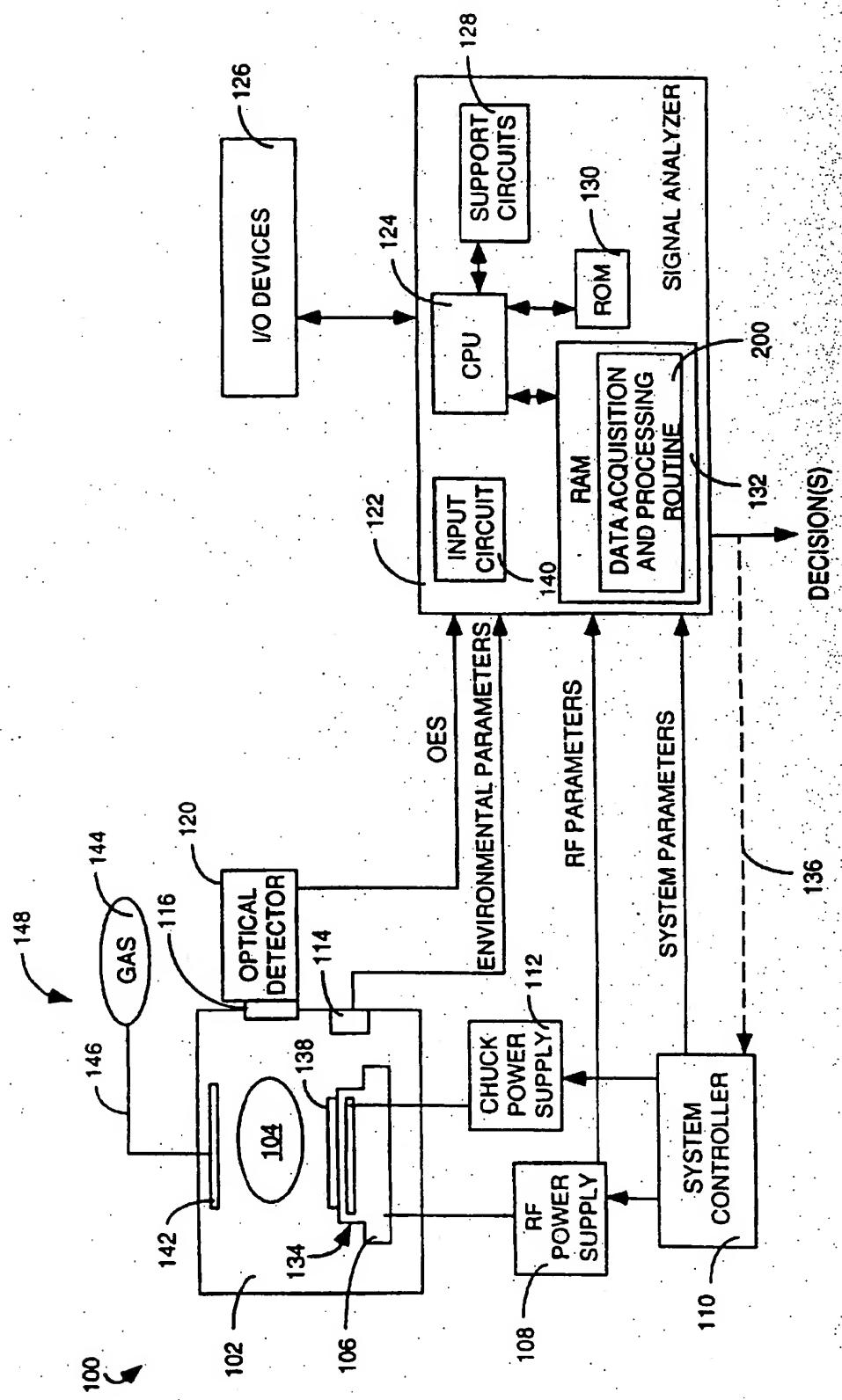


FIG. 1

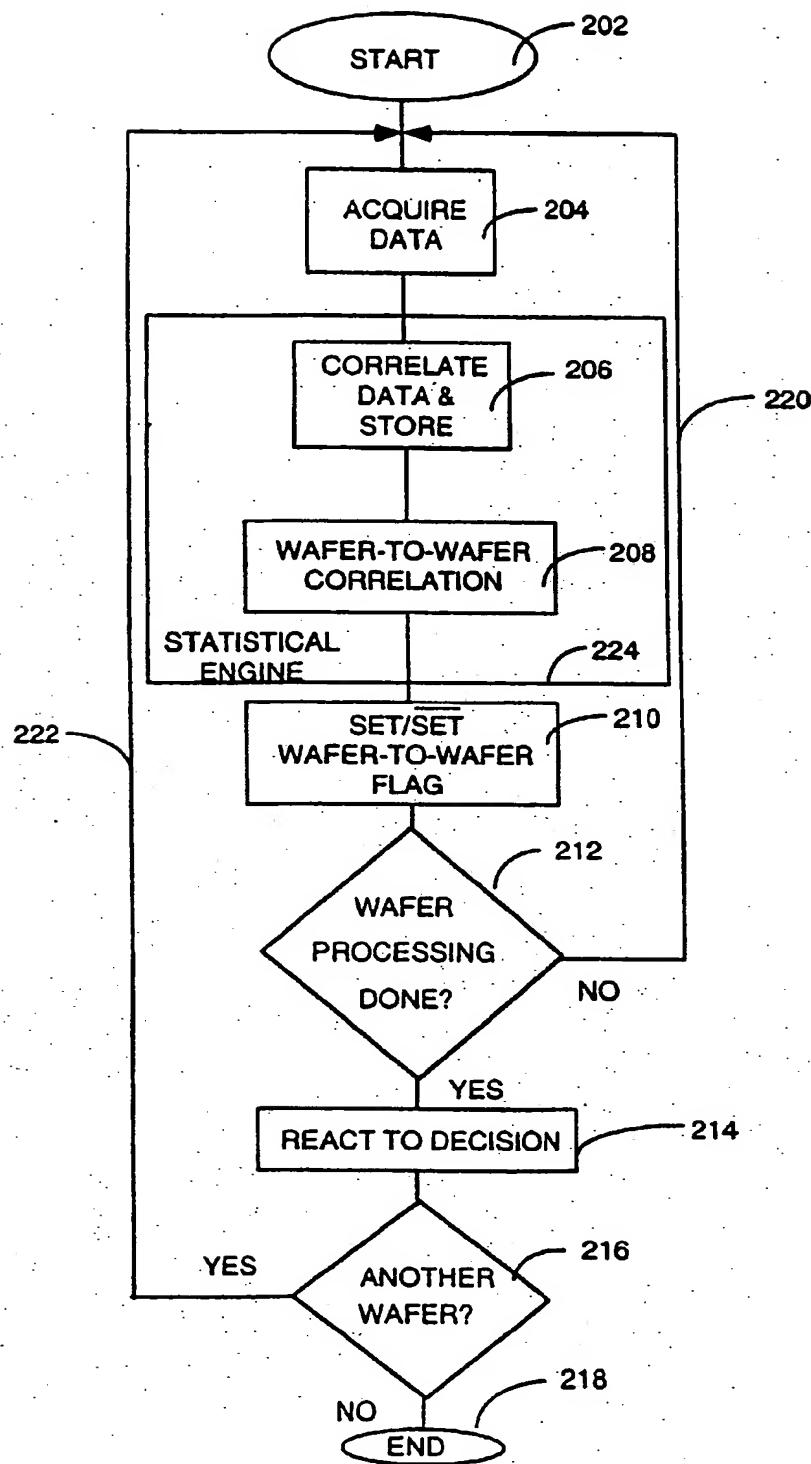


FIG. 2



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EUROPEAN SEARCH REPORT

Application Number
EP 98 30 3722

DOCUMENTS CONSIDERED TO BE RELEVANT			
Category	Citation of document with indication, where appropriate, of relevant passages	Relevant to claim	CLASSIFICATION OF THE APPLICATION (Int.Cl.6)
X	US 5 444 637 A (SMESNY GREG A ET AL) 22 August 1995 * column 1, line 53 - column 2, line 22 * * column 2, line 60-66 * * column 3, line 58 - column 4, line 35 * * column 5, line 23-65; figure 2 *	1,2, 5-10, 13-16,20	H01L21/66
X	US 5 497 331 A (IRIKI NOBUYUKI ET AL) 5 March 1996 * column 9, line 10-30; figure 1 *	1,2, 8-10,16, 20	
X	US 5 479 340 A (FOX EDWARD P ET AL) 26 December 1995 * column 1, line 44-64; figure 1 *	1,3,4, 9-12,16, 17,20	
X	US 5 467 013 A (WILLIAMS NORMAN ET AL) 14 November 1995 * column 1, line 30 - column 2, line 11 *	1,2,4, 8-10,12, 16,20	TECHNICAL FIELDS SEARCHED (Int.Cl.6)
A	US 5 320 880 A (DOAN TRUNG T ET AL) 14 June 1994 Entire document	1-20	H01L
The present search report has been drawn up for all claims			
Place of search THE HAGUE	Date of completion of the search 24 July 1998	Examiner Odgers, M	
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